GRAVITY WAVE OVER NEW ENGLAND, APRIL 12, 1961

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ABSTRACT

The movement of an unusually rapid rise in the atmospheric pressure approaching nearly 5 mb./hr. at its peak intensity is traced over the New England area using hourly surface data. The observed propagation speed of the pressure rise is in generally good agreement with the theoretical speed of a gravity wave as computed with the aid of radiosonde reports in the area. No significant or unusual weather was reported with the passage of the wave, although a few stations in the vicinity reported wave-type middle clouds during the morning and early afternoon.

1. SYNOPTIC SITUATION

An unusual rise in pressure was noted on the M.I.T. Department of Meteorology microbarograph during the early morning of April 12, 1961. The fact that no stormy or squally weather was observed at the time aroused the author's curiosity to investigate the phenomenon in greater detail. Study of the 3-hr. tendencies reported by the network of hourly reporting stations in and around New England revealed an area of unusually large pressure rises moving across the region in a generally northeasterly direction.

The surface synoptic pattern consisted of a fairly deep Low moving slowly eastward from Nova Scotia and a narrow ridge through the Mid-Atlantic States. A rather vigorous Low was moving eastward in the lower Mississippi Valley, preceded by an active overrunning squall line. The main features are shown in figure 1. The pattern is such that the pressure rise over New England could not have been caused by the rapid movement of a small, intense Low or sharp trough as reported by Tryggvason [1] and Emerson [2]. Since the direction of movement of the pressure rise was nearly perpendicular to the winds in the lower and middle troposphere, it could not have been an advective feature.

The presence of the squall line in the South suggests that the pressure wave may have been associated with the outbreak of convective activity over eastern Texas late in the afternoon of the preceding day. The 0100 and 0700 EST positions of the pressure rise are shown by dashed lines in figure 1, as well as an extrapolated position for 1900 EST the day before. The extrapolation was made with allowance for the orientation of the winds in the 850- to 700-mb. layer relative to the direction of propagation of the pressure rise, since the macroscale movement of the air in which the disturbance was embedded would contribute to its apparent motion. With the aid of the 6-hr. positions of the squall line, also shown in figure 1, it can be seen that squall line and pressure surge line would have been in fairly close proximity late in the afternoon of the previous day.

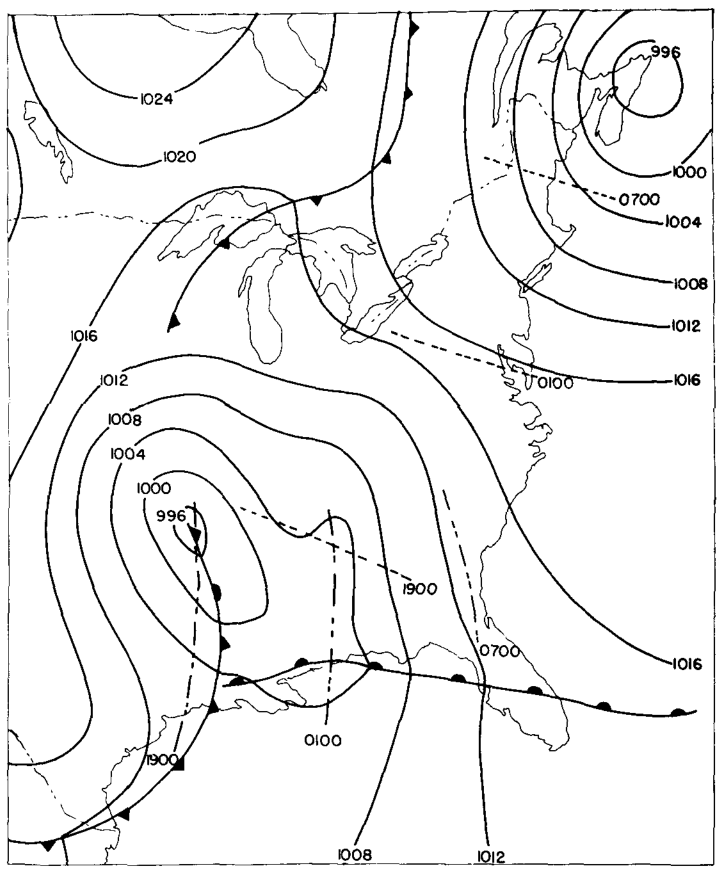


FIGURE 1.—General synoptic situation at 0100 EST, April 12, 1961. Observed and extrapolated positions of the pressure rise (short dashes) and squall line (long and short dashes) are also shown at 6-hr. intervals.

This type of situation has been suggested by Pothecary [3] as a mechanism for triggering gravity waves on an inversion or frontal surface, and may be similar to certain aspects of the situation analyzed by Brunk [4]. In the latter cases, however, the disturbance resulted in wind fluctuations at the surface, whereas only the pressure seemed to be affected in the New England example discussed here. It is interesting to note that Tepper [5], on the other hand, postulates that the pressure jump is first caused by acceleration of a cold front, and the pressure jump then triggers a squall line in a suitable air mass.

2. ANALYSIS AND DISCUSSION

In order to obtain as fine resolution in space and time as possible, without obtaining microbarograms for each station, the 1-hr. changes in pressure at stations in the area of interest reporting on Service A teletypewriter were computed from all available observations during the period 0100 to 1200 EST, April 12, 1961. Isallobars were drawn with some smoothing, allowing for reasonable errors in the readings of the barometer. A few reports were assumed erroneous, as when two stations within the same city area had indicated 1-hr. changes differing by a millibar or more.

The 1-hr. pressure changes are shown in figures 2A, 2B, and 2C at times near the beginning, peak intensity, and end of the pressure rise, as detected in the Northeast. During its earlier stages, the pressure rise was preceded by an area of falls of similar magnitude, but by the time it reached Maine, the falls were negligible. This may be attributed partially but not entirely to superposition of the normal diurnal rise in pressure. A small amount of rise may also have been due to slow eastward retreat of the Low near Nova Scotia. Nevertheless, the isallobaric gradient clearly had a maximum around 0600 EST, as seen from the entire series of pressure change maps (not all shown here). When the rise had reached the Gulf of St. Lawrence, its magnitude had decreased to only a little over 2 mb./hr. and it appeared to be flattening out in its spatial dimensions.

The hourly positions of the axis of maximum pressure rise are shown in figure 2D. The speed of propagation was found to vary between about 50 and 85 kt., with the fastest rates of travel around 0200 and 0700 EST, a slight retardation around 0400 and 0500, and a more marked slowing after 0900. Part of the variability in speed may have been spuriously introduced by the analysis, but most of the variation is probably real.

The velocity of the pressure rise area suggests that it was a gravity-wave type of phenomenon. A preliminary check of the morning radiosonde observations indicated a fairly strong inversion at most of the stations where the pressure rise was pronounced, and isothermal or markedly stable layers at several other stations in the vicinity. The lower tropospheric soundings for New York, Albany, Nantucket, Portland, and Sable Island are shown in figure 3.

The air at New York and Albany had evidently subsided throughout the layer from 600 mb. to 800 mb., producing a stable lapse rate through this depth. Farther east at Nantucket, the stable layer was more concentrated into a marked inversion, and the effects of subsidence were again present. At Portland and Sable Island the air was generally moist at all levels because of the proximity of the Low, but inversions were noted at these stations also, suggesting that a remnant of lifted tropical air may have been present following the earlier occlusion of the Low. Very little, if any, subsidence had occurred in this area. A nearly moist adiabatic lapse rate extended for almost 2,000 ft. above the inversion at Portland.

The structure of the inversion is better displayed by means of cross-sectional analysis derived from the soundings. The thermal structure of the atmosphere along the direction of propagation of the pressure rise is shown in figure 4A and a section normal to this through central New England is shown in figure 4B. The principal inversion slopes down toward the south and west, and is most marked over central New England. It is interesting to note that the pressure rise was most intense in this same area where the inversion was strongest. A second, weaker inversion may be traced at higher levels from central New England to the south and west.

Theoretical speeds were computed from several of the soundings, using the wave velocity formula.

$$c=\sqrt{\left(1-\frac{\theta_1}{\theta_2}\right)gh}$$

as found in table 1 of Tepper's article [5]. The computed speed was obtained by designating as θ_1 the mean potential temperature of the atmosphere from the base of the inversion or stable layer to the surface, and as θ_2 the mean potential temperature from the top of the inversion or stable layer to the 500-mb. level. The choice of this upper level was not too critical, as the lapse rates were generally quite steep from 500 mb. to the base of the tropopause. The height of the middle of the inversion or stable layer was designated as h.

For example, at Nantucket (fig. 3C), the inversion was judged to extend from 790 mb. to 745 mb., centered about 2.3 km. above the ground. The mean potential temperature of the layer from the ground to the base of the inversion was 280° K., and from the top of the inversion to 500 mb. it was 302° K. With these values, the formula in Tepper's article gives a computed value of 78 kt. for the speed of propagation of a gravity wave. Since this formula is for an ideal atmosphere consisting of two uniform layers of potential temperatures θ_1 and θ_2, separated by an inversion at height h above the ground, exact agreement with observed speeds would not be expected. There was fairly good agreement, however, as seen in table 1.

Theoretical speeds as corrected by the advective component of wind are shown in parentheses. The advective

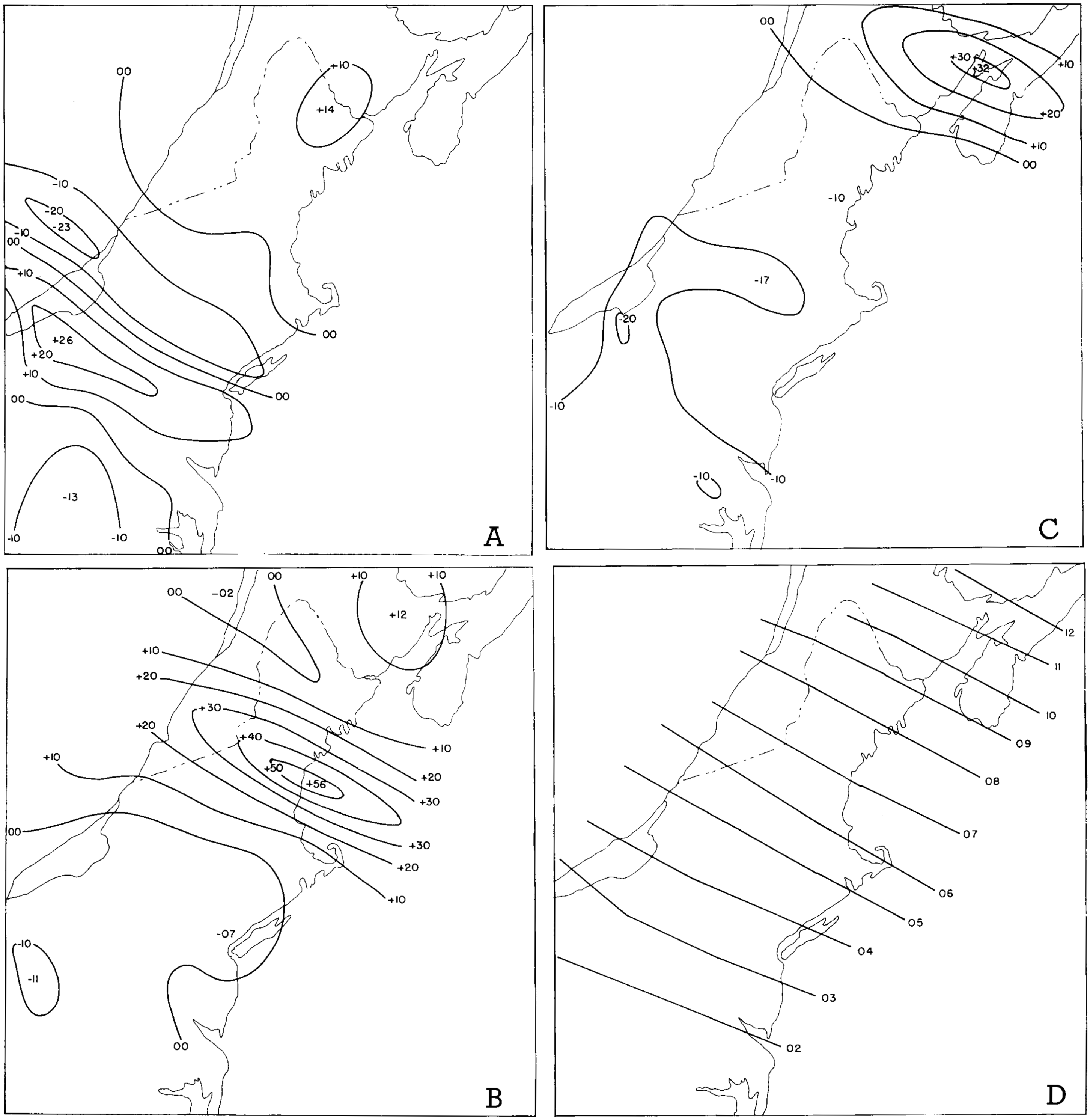
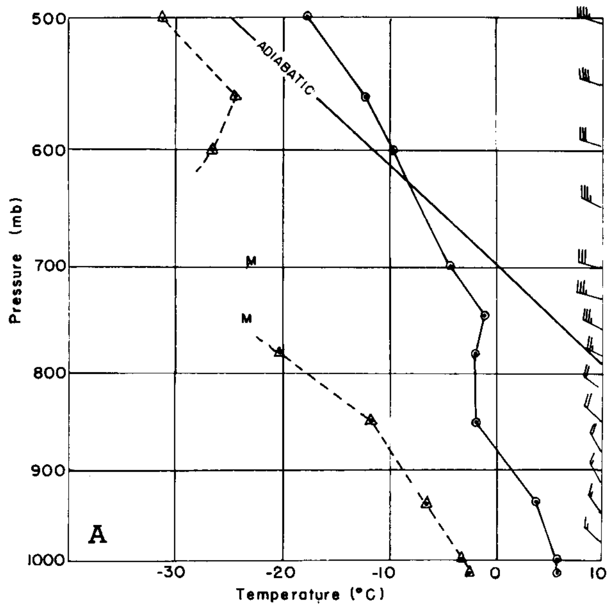


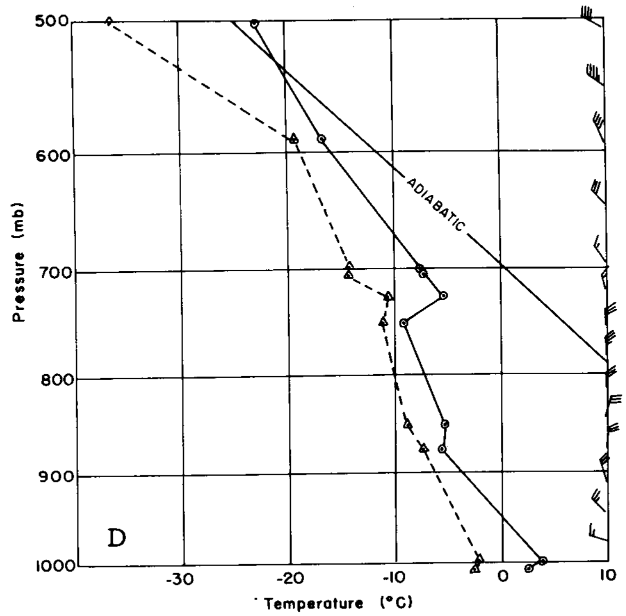
Figure 2.—Movement of the pressure rise across New England and adjacent areas, showing 1-hr. pressure changes in millibars and tenths, at (A) 0300 EST, (B) 0700 EST, (C) 1100 EST. The positions of the line for each hour are shown in (D).

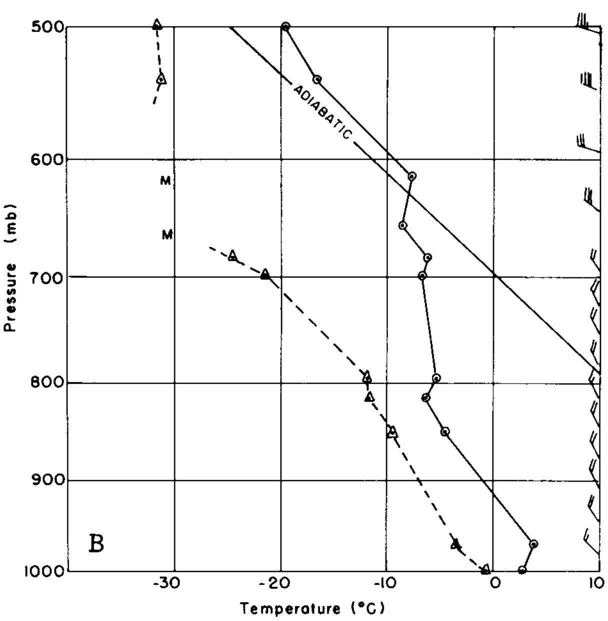
correction appeared to make no significant overall improvement in the correlation of the observed and theoretical values. It should be remembered that the time of passage of the pressure rise was in some cases a few hours earlier than the time of the sounding, although probably no major changes in the atmospheric structure occurred in so short a time.

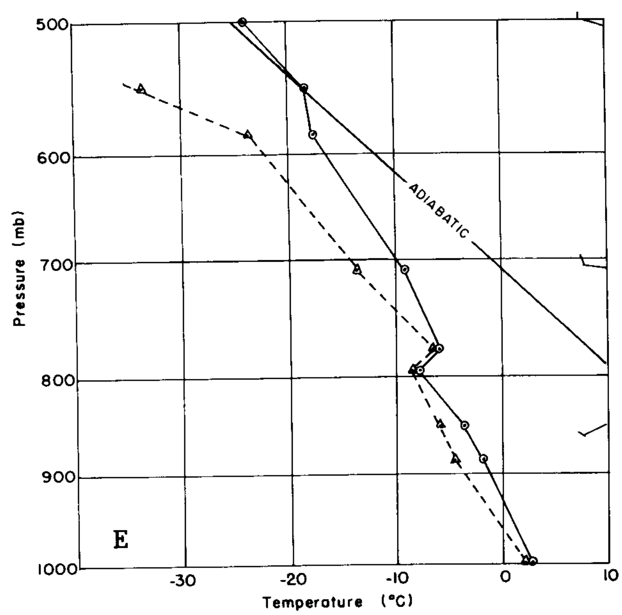
Microbarograms were obtained from Hartford, Boston, and Portland in order to examine the detailed structure of the pressure rise. The pertinent parts of the 24-hr. records were carefully reconstructed (fig. 5) since the photocopies were not clear enough for reproduction.

It is encouraging to see that the speed of propagation of the gravity wave from Hartford to Portland is 68 kt









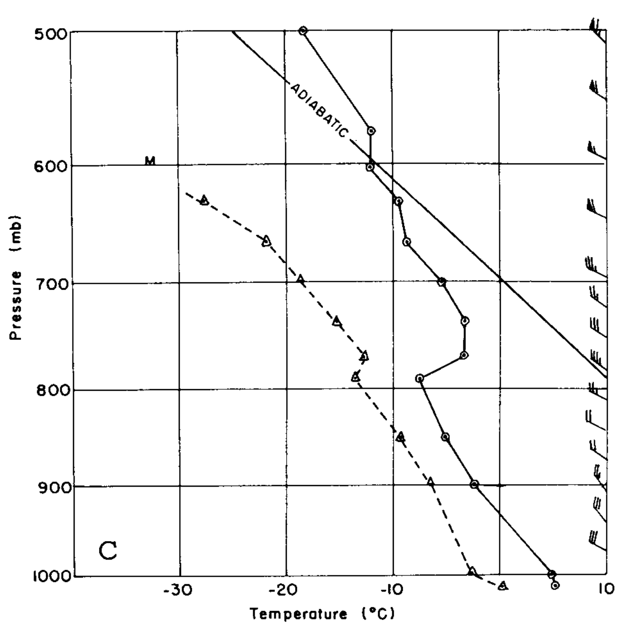


FIGURE 3.—Lower tropospheric soundings at 0700 EST for (A) New York, (B) Albany, (C) Nantucket, (D) Portland, and (E) Sable Island.

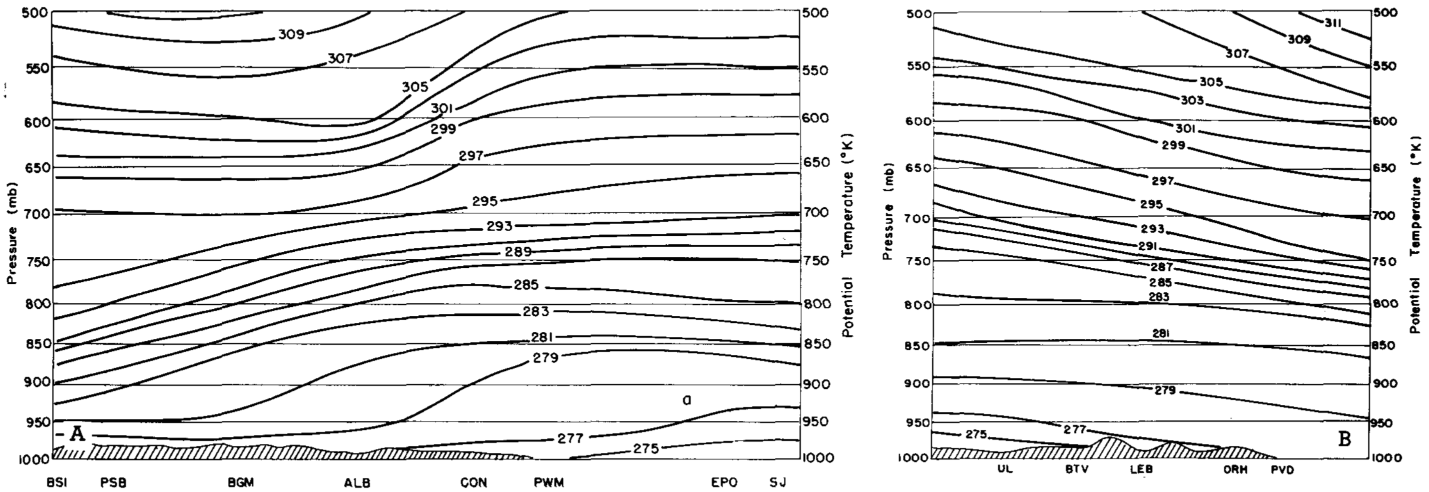


Figure 4.—Lower tropospheric potential temperature cross sections (A) along the direction of propagation of the pressure rise, and (B) at right angles to it near the area of maximum intensity. Call letters of stations within approximately 50 mi. of the cross section are shown at the bottom. BSI = Blairsville, Pa.; PSB = Phillipsburg, Pa.; BGM = Binghamton, N.Y.; ALB = Albany, N.Y.; CON = Concord, N.H.; PWM = Portland, Maine; EPO = Eastport, Maine; SJ = St. John, New Brunswick; UL = Montreal, Quebec; BTV = Burlington, Vt.; LEB = Lebanon, N.H.; ORH = Worcester, Mass.; PVD = Providence, R.I.

as determined from the times of onset of rapid pressure rise on the microbarograms. This is in good agreement with the values in table 1. It can be seen that the rise was made up of a series of somewhat irregular pulsations of shorter period which averaged about 13 min. at Hartford and Boston. The shorter period could not be traced in the Portland record, where unfortunately part of the trace was missing during the time of rapid rise. These oscillations are apparently of the type which were analyzed and discussed by Gossard and Munk [6], [7]. The period of these shorter oscillations is in fairly good agreement with a theoretical value of slightly over 10 min. computed from the Portland sounding, according to equation (8) in Gossard and Munk's paper [6].

Scanning of a series of M.I.T. microbarograms revealed several days with noticeable short-period oscillations in the trace. It is assumed that these are gravity waves too, although their period is generally too short and their amplitude too small for them to be synoptically analyzed from the available network of hourly reporting stations.

Comparison of the microbarograms in figure 5 shows that the rate of pressure rise increased as the wave progressed from Hartford to Portland. The rate, averaged over the time from the beginning to the end of the marked rise, increased from 2.1 mb./hr. at Hartford to 2.3 mb./hr. at Boston, reaching 4.2 mb./hr. at Portland (corrected for diurnal variation.) At Portland the entire rise occurred in only an hour and a quarter.

It would be tempting to liken this increase in the rate of pressure rise to the steepening of an ocean wave as it approaches a sloping beach. However, the orientation of the inversion surface and underlying topography (fig. 4A) indicates that the depth of the lower atmospheric layer actually increased slightly in the direction of propagation from Hartford to Portland. No immediate explanation can be offered for the change in shape of the pressure rise.

Table 1.—*Comparison of observed and theoretical speeds of the pressure rise*

Station	Observed speed (kt.)	Theoretical speed (kt.)
New York	80	73 (77)
Albany	78	95 (90)
Nantucket	57	78 (82)
Portland	78	76 (64)
Sable Island	*52	*62 (54)
Maniwaki	77	74 (68)

*Values estimated about 300 miles west of station.

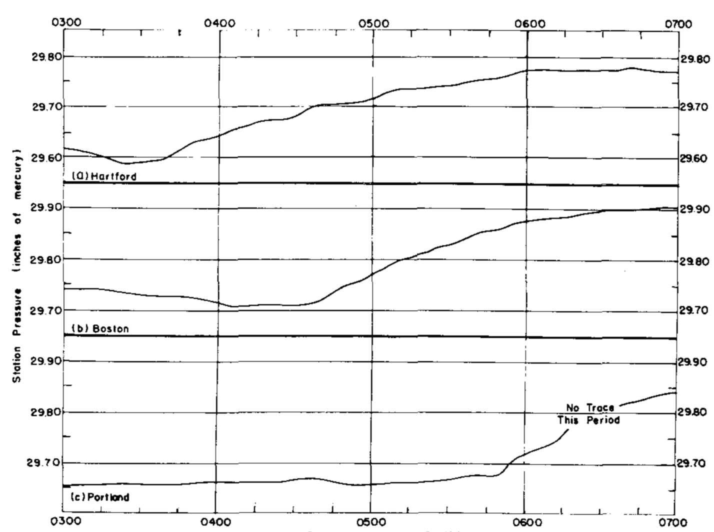


Figure 5.—High-speed microbarograph traces for (a) Hartford, (b) Boston, and (c) Portland shown on a simultaneous time scale.

A few hours after the pressure rise occurred, wave clouds were observed at M.I.T. A check of the synoptic observations for 0700 and 1300 EST in the area of interest showed only one station reporting middle clouds of type three or four, which might be construed as indicating gravity-wave motion in the atmosphere. This one station was Quebec, which reported altocumulus lenticularis at 1300 EST. Other stations reported more common types of altocumulus, and at a few locations low clouds obscured the sky. It is interesting to note that there are several points of similarity between some of the soundings in figure 3 and the sounding over Washington, D.C. on November 30, 1959, when an unusual wave cloud and a disturbance in the pressure were observed [8].

No unusual short-period fluctuations in wind speed or direction, or other atmospheric phenomena of the types reported in [3], [4], [6], and [7] were reported in the data used for this study. This is not to say that such phenomena did not, in fact, occur. Their occurrence would probably not be reported unless considered significant for aircraft operations. One station did report a light and variable wind, but this by itself was not necessarily due to the gravity wave. The author would be interested to know if any observers did note unusual variation of atmospheric parameters (other than pressure) on that date.

3. SUMMARY

The unusual pressure rise which moved across New England and adjacent areas during the morning of April 12, 1961 was evidently a gravity-wave type of phenomenon remarkable for its rather large amplitude and persistence over several hours. Theoretical speeds calculated from the upper-air soundings are in satisfactory agreement with the observed speeds determined from an hour-by-hour analysis of the pressure changes. The pressure rise reached maximum intensity in the area where the inversion in the overlying atmosphere was most marked. The large pressure rise was seen to be made up of shorter rises whose average period was also in agreement with the theory. No unusual weather except for a couple of observations of wave clouds was reported during or near the time of passage of the pressure rise. Analysis of the structure of the lower troposphere in the area showed a widespread stable layer or inversion topped by a layer of relatively small stability. This type of atmospheric structure has been found in other instances when short-period pressure pulsations and wave clouds have been observed.

ACKNOWLEDGMENTS

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